Pacific Fisheries Resource Conservation Council
Conseil pour la Conservation des Ressources Halieutiques du Pacifique

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Background

The "objectives" identified in the terms of reference for the Pacific Fisheries Resource Conservation Council include the development of strategic advice regarding stock conservation and enhancement. The Council is expected to advise the ministers and the public on the status of fish populations, identify stocks in need of conservation, identify appropriate conservation actions, and identify stocks where there is insufficient information to assess their status. The Council is also expected to review and make recommendations pertaining to research and monitoring programs.

The status of salmon stocks in British Columbia is poorly understood. The most recent attempt at providing the public with a picture of the state of BC's salmon stocks was a 1996 study undertaken by four Canadian scientists associated with the North Pacific Chapter of the American Fisheries Society. That study illustrated the significant "information gaps" encountered in efforts to determine the status of BC salmon stocks. While the scientists managed to identify 9,662 salmon stocks in BC and the Yukon, assessments were possible for only 57 percent of the stocks, and those assessments were often based on unreliable and outdated data. Still, of the 5,487 stocks where assessments were possible, the authors of the 1996 study concluded that 142 stocks had been rendered extinct in the 20th century, 624 were at high risk of extinction, 78 were at moderate risk of extinction, and 230 stocks were considered of "special concern."

The PFRCC, in this first report, intends to provide a broad species-by-species overview of stock status and trends for BC as a whole, as well as an overview of the relevant fisheries management issues associated with determining stock status. The initial aim is not to provide a detailed or complete enumeration of all local conservation issues, but rather to highlight major concerns, and to identify needs for more detailed analysis.

We begin with a discussion of biological diversity in salmon, the "stock concept" and its scientific uncertainties, and how these issues relate to sustainable fisheries management. We then describe the methods Fisheries and Oceans uses to assess abundance and productivity, and to establish spawning stock and exploitation goals. This is followed by a broad species-by-species overview of stock status and trends. We then provide a review of the issues involved in harvest regulation, focusing on the compromises that occur in balancing fisheries production, protecting biological diversity, and setting allocation goals. Finally, we discuss the benefits and pitfalls associated with developing alternative strategies for rebuilding weak stocks and ensuring sustainable harvest management.

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Biological Stock Structure: The Staggering Diversity in Salmon Population

In any attempt to assess salmon stocks, a major challenge exists in determining just what we should regard as a single "stock," "population unit," or "evolutionarily significant unit" of a salmon species.

At the species level, British Columbia is home to six species of salmon — chinook, chum, coho, pink, sockeye and steelhead. Because the members of each of these species spawn in freshwater, but spend some of their lives in the sea, they are known as "anadromous" salmon. Members of the five "Pacific salmon" species die after spawning, but the steelhead salmon (sometimes called a trout) is a sea-run rainbow trout that may survive to spawn several times.

Over the thousands of streams and lakes where they spawn, salmon have developed a remarkable diversity in their life histories and in the way they have adapted to local circumstances. This diversity is critical from a resource production perspective, because in production terms, "adaptation" means producing the most offspring possible for each type of environmental pattern that the fish can utilize. Indeed, there are many thousands of what biologists call "demes," collections of individuals that have been precisely selected to best use local habitat conditions.

The popular view is that salmon and steelhead always have near-perfect homing abilities, returning to spawn precisely at the same place in the very stream where they were spawned, so that the fish returning to every tiny stream along the coast may be "specialized" to best use just that tiny stream. But from hatchery studies, we know that salmon can "evolve" very quickly. Inherited behaviour can be changed through natural selection over just a few generations. Behaviour changes can also be induced by artificial selection. A salmon population can be manipulated, for example, by selecting for the earliest or latest spawners, to shift by a month or more the time of year when the fish run upstream.

In wild populations, we see the results of specialization and selection for local adaptation in a myriad of ways. Tremendous variation occurs in the time of year when adult salmon spawn, in the kind of habitat juvenile salmon use after hatching, in the amount of time juveniles spend in freshwater, in where salmon move when they go to sea, in the ways they return from the sea and when they return. Chum and pink, for instance, spend a few weeks in freshwater before their seaward journey, but some races of steelhead spend several years at a time in freshwater. Chinook and coho tend to hug the coast and mainly move northward

when they reach saltwater, but sockeye, pink, and chum migrate far out into the North Pacific.

Sometimes, we can see just why particular characteristics have been favoured. Sockeye that spawn in the cold headwater streams of the Fraser River usually lay their eggs very early, in September, so that their eggs will hatch early enough, in January, so that the fry can move deep into the gravels to avoid freezing in the ice of winter. Chinook salmon that spawn far up the larger rivers (known as spring salmon, or summer chinook) generally have juveniles that rear for a year in freshwater, presumably because small fry cannot survive the rigors and predators of a long downstream migration to the sea. Fall chinooks, in contrast, spawn in rivers near the sea, and their offspring generally make the journey to sea within only a few months after hatching.

There is considerable uncertainty and debate among biologists about how to go about the challenge of conserving diversity within salmon species, and about just what constitutes a single "stock," or "population unit," or "evolutionarily significant unit" of a salmon species. Part of the problem is that, despite the popular view, not every salmon returns to the precise place it was spawned. It is not always just natural selection that drives the evolution of precise homing abilities. This is particularly true for salmon that spawn in very small streams, where environmental conditions are unpredictable even under natural conditions, and where an advantage may exist in an ability to disperse and find new spawning sites.

To understand this diversity issue, we need to think back to the end of the Pleistocene glaciation, about 10,000 years ago, when the great ice sheets that covered much of what is now British Columbia were retreating to open up vast stream and lake habitats for fish. Salmon that had a tendency to disperse and colonize new habitat would have been favoured by these conditions over salmon that did not exhibit these tendencies. But down through the millennia, habitats became filled with salmon, and salmon competed for spawning and rearing sites. As the competition intensified, the advantage shifted to those salmon that specialized and produced the most offspring in each habitat. Under these conditions, salmon with the colonizing and dispersal tendencies held a diminishing advantage, as the chances progressively diminished that their offspring — "programmed" to disperse from the areas where they were spawned — would survive in their competition with salmon that specialized in producing large numbers of offspring in each habitat.

The great variation we see today in the homing patterns of Pacific salmon and steelhead was, to a great extent, determined by that ancient competition and natural selection between good colonization behaviours and good homing and competitive abilities.

Down through the ages, chinook salmon, which produce the largest-bodied salmon by far, eventually came to dominate many large, predictable spawning sites, very often below the outlets of lakes that act to stabilize downstream river flow conditions. Now, most chinooks home very precisely back to these sites, and chinook have also developed the greatest diversity of life histories among all salmon species. Specialization and precise homing also developed in many sockeye salmon races, again particularly for fish that spawn in larger, more predictable stream locations. But with sockeye, many fish show considerable ability or tendency to disperse at least among small spawning streams or shoreline spawning sites surrounding a particular rearing lake, so that it becomes unclear just what a sockeye "deme" is when we look at the many streams surrounding large lakes like Owikeno Lake, at the head of Rivers Inlet on BC's Central Coast, or Babine Lake, in the Upper Skeena watershed.

With the other species (steelhead, coho, pink, and chum salmon), we see some fish that are specialized to return only to particular, predictable spawning sites, especially in interior areas where the fish have a long upstream migration. But the bulk of the production for these species comes from smaller, coastal streams where spawning conditions are, at least to some degree, unpredictable. In coastal areas, we see considerable direct evidence (from tagging, shifts in spawning sites) of fish moving between spawning streams and tributaries of larger streams from ten to 50 kilometers away. Biologists interpret this behaviour as a form of natural selection which favours some animals that "test" changing habitat opportunities by having at least some offspring that tend to be "colonizers" rather than "stay-at-homes." In technical terms, this leads to what biologists call a "metapopulation structure."

A metapopulation structure in salmon occurs when there are lots of small populations and spawning sites where most individuals return, more or less to the place where they were spawned, but there is also "linkage" between these sites because of the regular dispersal (or weaker homing) of some individuals. Within such a metapopulation, "gene flow" takes place. Gene flow of traits like spawning timing, prevents precise specialization to be most productive for the particular habitat characteristics of each spawning site.

Biologists are just beginning to understand how such metapopulations are organized over the BC coastal landscape. By using methods such as DNA fingerprinting, biologists are finding some early indications for coho salmon which suggest that fish that spawn in streams with outlets less than 50 to 100 kilometers apart are likely to belong to the same metapopulation. However, within any such metapopulation there can still be highly specialized "runs" or "demes" of fish with unique characteristics, such as a tendency in juveniles to disperse upstream from a spawning site in order to rear in a nearby, relatively productive lake or river backwater area.

What does all this tell us about how to manage salmon on a sustainable basis for harvesting?

It is often argued that it is not economically justified to protect biodiversity at a level that demands close attention to the needs and risks associated with every spawning site that contains what we have come to call "weak" or "lesser" stocks, many of which may never be particularly commercially productive. The difficulty in this is that, over time, it has been easier and easier to use this approach as an excuse to ignore lesser stocks and concentrate on stronger and more commercially valuable runs, leading to progressive erosion of stock structures. The Council believes Pacific salmon habitat should be protected, and salmon fisheries managed, from the premise that localized spawning populations reflect genetic diversity and are valuable to the long-term maintenance of the salmon resource.

Conventionally, Fisheries and Oceans has considered whole collections of biological demes as single production units of "mixed stock" fisheries, because of the practicalities of management and the widely-held view that salmon are most commercially valuable well before they reach spawning streams. We clearly cannot protect, with absolute certainty, every fish population that uses every spawning site in BC except by not harvesting at all, or by harvesting only when fish enter these spawning sites.

Fisheries managers are faced with a trade-off that remains unresolved. To maintain a productive system, we need to protect the demes and local specializations that make the fish productive in the first place. If we try to protect all of this productive potential, we can only do so by: 1) harvesting at quite low rates in mixed-stock fisheries (missing potential harvest from the most productive spawning sites), 2) allowing considerable

"erosion" in genetic stock structure by overharvesting the fish from less productive spawning sites, 3) harvesting the fish only at spawning sites, after they may have lost much of their economic and recreational value, or 4) a mix of these approaches as appropriate.

Lacking clear direction about how to cope with what appears to be an unavoidable conflict between maintaining biological diversity and ensuring harvest value, federal fisheries managers have historically managed fisheries geared to the largest or most productive stocks. The recent curtailments in salmon fisheries aimed at protecting coho salmon bound for spawning streams in the Upper Skeena and Thompson rivers was a dramatic departure from this practice.

In some areas, the practice of ignoring smaller stocks has resulted in a drastic loss of stock structure in various salmon species by the early part of this century. Some fisheries now have little interception because non-target species have been fished down to a low level of abundance. For example, the Rivers Inlet gillnet fishery for sockeye salmon had low interception of other species, in part at least, because other species in the area at the time of the fishery have been fished down. In areas such as the Skeena River and the Fraser River, it is likely that the combination of early fishing and other factors greatly reduced biological diversity.

There have been conscious efforts to rebuild stock structure in these major rivers, and to protect many of the remaining stocks from overfishing. The number of days open to gillnet fishing on the Fraser River has been drastically reduced since 1970, from more than 60 days a year to sometimes fewer than five days. Some of this reduction has been aimed at protecting runs of sockeye and pink salmon (the main "target" species), but many closures were introduced to protect weaker sockeye stocks (especially the Early Stuart runs, which enter the river in July), chinook salmon (May-July closures to protect upriver "spring" chinook, and September closures to protect fall-run chinook), steelhead, and most recently, coho salmon.

We cannot say how much of the biological and productive diversity that developed after the Pleistocene epoch was lost during the first half of this century. There is a record of a systematic program of examination of spawning streams on an annual basis since the 1950s. Since the late 1980s, the number of streams and intensity of coverage has been reduced and there has been increased reliance on a few, more intensively monitored, index streams. If we do not look back carefully at early losses, we may be trapped in the "shifting baseline syndrome" (Pauly 1995), a common fisheries management problem around the world: too often fisheries managers use only recent data as evidence of population stability, management "success," or productive capability when, in fact, there have been many previous cumulative losses that the recent data do not reflect.

Based on declines of stocks and habitat losses, much of the original genetic diversity likely has been eliminated. Between 1950 and 1990, systematic spawning checks undertaken by Fisheries and Oceans field staff indicated that three species (coho, chum, chinook) were not reported in about 20 percent of the spawning sites where they were found during the 1950s. Pink salmon have disappeared from about 10 percent of the sites. In the Fraser, on the other hand, sockeye are being recorded at more sites than formerly. Mainly, the disappearances have been from small streams with high natural variation in potential productivity — streams that are also the most vulnerable to habitat damage by various human activities. At least some of these disappearances may reflect changes in surveillance policy and resources (i.e. not visiting some streams) rather than real biological losses.

What follows is a description of methods used by DFO to assess abundance and productivity, and to establish spawning stock and exploitation goals. These methods are a key limiting factor for evaluation of stock status, because assessment data are very poor for most of the spawning runs, especially smaller ones. These small runs contribute to biodiversity and future conservation concerns and are most at risk from habitat change, yet we have only very crude trend information gathered through such annual "inspections" as fisheries officers may have undertaken. For most spawning runs we also do not know how many fish were caught, since most runs are harvested only in fishing areas where fish from many runs are mixed, and for which it has been impractical to routinely measure contributions of individual runs.

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Methods for Assessment of Spawning Runs

It is probably unrealistic to expect government agencies to gather and maintain detailed and accurate escapement statistics for every one of the thousands of salmon spawning runs in BC Fisheries and Oceans staff have nevertheless struggled to conduct annual inspections since 1950 for a high percentage of all salmon species spawning areas. There is also some escapement information from scientific and stream guardian programs going back to the turn of the century. Relatively accurate escapement time series data have been obtained for some economically important runs (particularly sockeye), and for "index" small runs (like Black Creek coho near Comox on Vancouver Island) that are thought to be representative of regional trends.

Total spawning number estimates are obtained by a variety of techniques. Roughly in order of increasing accuracy, these are:

(1) Single-visit visual inspections. A fishery officer or biologist drives to index counting points, walks a stream, or flies along it in a helicopter, and makes a single count of all fish visible. Sometimes this involves sweeping a net through likely sites in deep or turbid streams, or "pitching" spawner carcasses. These counts are expanded by factors to account for the proportions of the total run not in the stream at the time of the count (already dead or yet to arrive); proportions of the stream not visited, and proportions of fish not visible (especially for coho, since a high proportion of the fish at any moment are likely to be hiding under debris or cut banks which they are very good at). The overall "expansion factor" may be anything from a sheer guess to a careful calculation based on comparing the visual counts to some more accurate and complete procedure. Often, field staff lack time or resources to make return visits. Also, equipment problems, high turbidity due to a high rainfall or flooding, and other pressing work tasks routinely interfere with making the counts. Unfortunately, there has been considerable inconsistency in the way field staff have estimated and reported spawner counts between years and between stocks. In some cases it is not clear if annual inspections were not made or no fish were observed. Also, there may be no good basis for developing expansion factors. In extreme cases, it appears that some staff have simply reported the same number year after year without apparently even visiting a stream. Changes in field staff and in procedures have also led to inconsistencies in counting methods and expansion factors over time. Unfortunately, staff have not been required to record precisely where and how each inspection was done, and what expansion factors were used in final reporting. Consequently, in most cases we cannot even look back at the history of observation and apply improved correction factors for situations where such factors have been obtained.

(2) Multi-visit visual inspections. The same basic counting methods are used as in (1), but are carried out several times during the run so that total numbers can be estimated by a procedure which takes into account new arrivals and deaths during the spawning period.

(3) Swim surveys. These are similar to visual inspections, except that staff swim down as much of the river as possible while counting fish. In clear water systems, swimmers generally see a much higher percentage of the total fish actually present, especially for secretive species like coho. Occasionally, the swims are done multiple times to provide more data for analyses. For example, this is now done for a collection of chinook runs to West Coast Vancouver Island streams.

(4) Mark-recapture estimates. In this method, people tag or mark as many of the spawning fish as possible, then later examine fish (usually carcasses) to obtain a ratio of marked to unmarked fish. The ratio is expanded by the number of fish initially marked to provide a total population estimate. Multiple marking/recapture episodes are occasionally used to increase the accuracy of the procedure, and to estimate spawner turnover (time on spawning beds before being replaced by another wave of spawners). This is the main spawning ground assessment method for some of our largest salmon runs, including most Fraser River sockeye and Harrison River chinook.

(5) Acoustic estimates. In this method, fixed or vessel-mounted sonar systems are used to obtain a total count of fish passing some index point, and independent sampling is conducted to determine species composition of the "echoes" where and when necessary. This technology has evolved considerably, from simple systems that just counted every passing object (including logs and other debris) to dual and multibeam systems that allow analysis of target size and movement pattern so that false targets can be filtered from the data. Automated systems are being tested that can be installed at remote locations and left to record fish passage over extended spawning runs. Acoustic systems have been a tool for assessment and in-season harvest management in the Fraser system and in the past at Rivers Inlet.

(6) Counting strips and fences. In this method, the fish are directly counted as they migrate upstream, either by watching them pass over a counting strip on the river bottom (as is the case for Atnarko River pink salmon in the Bella Coola system), or by using a fence to force them through a restricted counting channel or trap. Fence systems range from simple "broomstick" affairs to massive structures. Small-scale examples of this method are applied in small streams (such as Black Creek, on Vancouver Island), where structures can be removed during floods, and fish missed during such events may be assessed by mark-recapture methods. At the other end of the scale is the facility known as the Babine Fence, which provides counts for most fish reaching the upper Skeena River system. A similar counting facility is in place at the point where sockeye enter Long Lake at the head of Smith Inlet.

These methods are applied in widely differing ways, for different species, and in different areas of the province.

Procedures (4-6) are used mainly for sockeye salmon (the only large sockeye run that does not pass through a fence or acoustic counting system are fish returning to Owikeno Lake, at the head of Rivers Inlet), and cross-checks on acoustic estimates for Fraser runs are provided by further mark-recapture procedures at the spawning grounds.

Only a few wild chinook salmon runs are enumerated accurately through fences, mainly runs that chance to pass fence sites intended primarily for sockeye assessment. Mark-recapture procedures may be providing good estimates for a few large chinook runs, such as the Harrison River run in the Fraser system, but these estimates have not been checked or validated by other procedures.

A few large pink salmon runs are well estimated, again mainly by procedures developed originally for sockeye assessment.

The importance of improved escapement information

The Harrison River chinook salmon, most likely the largest chinook salmon run in BC, provides a good example of how inadequate investment in monitoring stocks eventually comes back to haunt us. Available data tell us two completely contradictory stories about what is happening to the stock, as shown in the attached figure.

First, fishery statistics would suggest that something is deeply wrong with the stock. Harrison River chinooks were historically a dominant component of the "white spring" (white-fleshed) catch off the BC south coast. Until the 1980s, white springs made up close to half the Georgia Strait sports and troll catch. Then, the Strait of Georgia catch and exploitation-rate statistics, along with September gillnet catch-per-effort for the Fraser River (Harrison chinooks were a dominant component of that catch until the 1980s), indicate that there was a dramatic decline in total chinook abundance. This was accompanied by a decline in the proportion of white springs in the catch (top panel of figure). We can reconstruct roughly how many chinooks had to be in the Strait of Georgia each year in order to account for measured catches and escapement-catch ratios. This reconstruction indicates a decline of at least 80 percent from 1975 to the present.

But reasonably accurate escapement statistics were not obtained from the Harrison run until 1984, when conservation concerns and U.S.-Canada treaty obligations led to the development of a mark-recapture estimation procedure. The mark-recapture method "discovered" roughly five times as many spawners as fishery officers had been recording for the stock, and estimates derived from the mark-recapture method do not indicate a consistent pattern of decline after 1984 (fishery statistics also indicate that most of the decline had taken place by that time). Obviously, we cannot directly compare the fishery officer inspection reports with the mark-recapture estimates when they differ so grossly. Worse, the earlier inspection data indicate exactly the opposite trend in escapement as we would expect from the fishery statistics — if we take the inspection records at face value, the spawning run was either stable or increasing over the period when fishery statistics would indicate considerable decline.

How should scientists and managers interpret such contradictory trend information?

One set of observations suggests there is a severe conservation problem, while the other suggests things are just fine. There are good reasons to be suspicious of both. Many factors can cause misleading trends in fishery statistics, and it is impossible to decide what basis fisheries officers had for recording

increasing escapements. So we cannot resolve the issue just by looking at the available data more closely. In the end, about all that can be done is to adopt a "precautionary approach" and introduce strong conservation measures, at least until it can be determined whether things are as bad as indicated by the fishery statistics.

In this example, the cost of poor data is not just measured in terms of the risk of making a bad decision about harvest management. In the Georgia Strait setting, scientists have also been pressed to advise about whether the herring fishery has had deleterious impacts on chinook and coho production. To provide such advice, scientists must look to the history of the stocks for evidence of impact — it is not enough to demonstrate that chinooks eat herring, because chinooks eat a lot of things, and in fact may compete with herring for plankton food when they are small. In principle, it should be easy to provide evidence to support the assertion that herring declines have had an impact on chinook populations. Herring stocks were badly depleted during the 1960s, by a "reduction" fishery in which the herring were processed for oil and fishmeal, so we should be able to look back and see whether that depletion led to reduced abundance of chinooks, including the Harrison stock. Indeed, when we plot herring spawn abundance trends alongside the escapement data (second panel of graph), there is an apparent correlation — chinook appear to have recovered after a 1950-70 low in step with the herring recovery, which scientists might interpret as evidence that chinooks need herring as food. But what about the fishery statistics? These indicate either no correlation, or a negative correlation between chinooks and herring. Does this mean that chinooks and herring are in fact competitors when chinooks are small, or that herring really aren't that important one way or the other for chinooks?

In short, the data are so poor that scientists cannot even determine the direction of the chinook-herring relationship. This means that any policy decisions about whether to practice "ecosystem management," by protecting herring to ensure food supplies for predators like salmon, will end up having to be based largely on speculation.

Consider another example. Suppose scientists are asked to advise about how much impact habitat alteration in the Harrison River watershed has damaged the chinook stock. Harrison Lake (upstream of the main spawning area) may have buffered some impacts of logging in the upper Harrison River watershed, but there is logging, as well as other development concerns, below the lake, as well. Again, what are scientists to say? One set of data indicates a possible deleterious impact of habitat disturbances ranging from logging to hatchery production, while the other suggests a healthy stock in spite of any such impacts.

Ultimately, the wages of poor escapement information systems extend far beyond issues of harvest management, and severely limit our ability to objectively determine the impacts of a wide variety of factors on salmon production and health. Ultimately, we will pay the price in terms of inadequate or unnecessary harvest regulations, failure to deal with ecosystem management issues effectively, or inappropriate responses to perceived habitat damage risks.

The very large number of smaller spawning runs of chum, pink, and coho salmon to coastal streams, where visual counting is particularly difficult, are mainly assessed with single visual inspections. Fence counts, meanwhile, provide better trend information for a few chosen coho streams (often called index streams),

mainly on the south coast.

Efforts are underway to provide accurate information for more small populations through cooperation with local enhancement and habitat-restoration groups, such as groups associated with the Streamkeepers program, and Aboriginal communities associated with the Aboriginal Fisheries Strategy. These efforts have not been in place long enough to provide trend information. Further, they generally involve situations where trends in wild-salmon populations are affected by enhancement and habitat improvement measures, and by the lack of scientific treatment/control comparison measurements. In other words, it is difficult to know whether the trend is natural or a result of enhancement or other measures.

The visual inspection program lacks clear standards, field instructions, "expansion factor" methods, and recording procedures. As a result, most historic spawner data provide a relative indication of stock abundance but are not useful for formal scientific stock assessment of the "productivity" of various salmon stocks. Such inaccuracies are likely to cause gross underestimates of proper escapement goals for healthy production — this is related to a statistical problem scientists call "errors in variables." This lack of good abundance data might make it progressively more difficult to justify and defend habitat protection measures.

Unfortunately, there has never been a concerted, coast-wide response to these problems. Even today, we cannot pick any particular stream for which a visual escapement estimate has been recorded, and obtain a precise accounting of just how many fish were actually counted and how or why these counts were expanded to provide the estimate finally recorded. Information about how earlier estimates were obtained has now been lost forever: field staff have retired, or have been reassigned, and the years pass. As a result, we most often cannot recover any basic stock trend information, correct for biases in past trends by using results from more recent assessment procedures, or conduct tests of counting procedures and expansion factors. In short, we don't know — in detail — what the province-wide status of stocks is.

Improvement of escapement assessment procedures is a matter of priorities. DFO field staff often do not have the time or the resources to make more field inspections, or record what they do see in detail, or carry out more intensive assessments to validate and calibrate expansion factors for the counts that are obtained. There is a trade-off between general (qualitative) coverage of as many stocks as possible versus a detailed (quantitative) coverage of a few stocks. For years, there have been warnings that poor data could ultimately lead to poor management, and to difficulties in justifying habitat-protection programs. Still, financial resources for field assessments have been reduced in recent years. An example is the Owikeno Lake "fall tour," in which fishermen and biologists cooperated, for many years, to obtain escapement information for the important Rivers Inlet sockeye stock. This program has recently been cancelled. Province-wide, about 20 percent fewer streams are now being visually inspected than was the case before 1990.

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Methods for Analyzing Productivity and for Setting Escapement and Exploitation-Rate Goals

To estimate the "productivity" of a stock, it is necessary to have accurate, year-by-year information about the number of the stock's fish that were caught, and the number of the stock's fish that spawned. The "productivity" of a stock is measured by determining the ratio between the number of spawners and the resulting adult production (catch plus escapement). Sometimes, to determine a stock's productivity rate, it is also necessary to know the age composition of the returning production.

Understanding a stock's productivity rate is of crucial importance when making decisions about how many fish should be caught and how many fish should be allowed to spawn. Obtaining the necessary information to determine a stock's productivity can be difficult. Without reliable "productivity" information, it becomes impossible to determine just how many fish of that stock can be caught without causing harm to the stock or diminishing the number of its potential "recruits" in the future. If any step in a productivity assessment fails, harm can result from ill-informed fisheries-management decisions.

The productivity ratio tells us how many "harvestable" fish a stock produces, and how many spawners are required to sustain the stock. Productivity ratios cannot be established without reliable, historical data. Productivity ratios can only be determined by relying upon direct field data and hard experience.

About all we know in general from hard experience is: (1) the productivity of salmon stocks varies considerably over time, due to environmental factors; and (2) on average, productivity is negatively related to spawning abundance — the offspring from larger spawning runs suffer higher mortality rates than offspring from lower runs, most likely due to competition for resources (spawning and rearing space, food, places to hide from predators).

We know this second point to be true, because we know salmon populations do not grow or decline indefinitely, showing no "limits" related to the availability of habitat resources. Therefore, productivity assessments are necessary in order to determine "optimum" escapements for various salmon stocks. Fisheries management requires not only productivity measurements, but also measurements recorded for enough years to see average differences in productivity associated with differing spawning-run sizes.

For a few populations, mainly of coho and sockeye salmon, detailed statistics are available for the egg-

production and life-stage survival rates which are components of productivity (i.e. egg-to-fry survival rates, fry-to-smolt survival rates, and marine survival rates, from smolt to adult). Analysis of these detailed statistics can sometimes explain why overall productivity is changing. For example, coho productivity has declined in recent years due to declines in marine survival rates, and declines in egg-to-fry survival rates have been measured when spawning beds are impacted by sediments from logging road construction, gravel extraction, etc. It makes biologists feel good to be able to provide such explanations, but in the end, management for sustainability must be based upon measurements of overall (cradle-to-grave) productivity, over the salmon's full life cycle, and upon reasoned responses to those measurements.

There is a popular misconception that the management of salmon fisheries begins by merely determining where and when the fish should be caught, and by whom. But salmon-fisheries management decisions must begin with analyses of biological production capability, in order to determine how many fish ought to be allowed to spawn, and what percentage of the fish can be safely harvested.

Salmon biologists and managers have used two quite different approaches to the challenge of analyzing escapement and productivity data in order to determine escapement and "exploitation rate" goals. The most common approach has been to simply plot the data as time trends, then make a "seat of the pants" or "eyeball" assessment of what escapement level seems to give the best return, and then figure out whether policies need to be adjusted to cope with some "temporary" period of unusually low or high productivity. A key danger in this approach is to confuse the apparent absence of trends over time with success at achieving productivity goals. It is all too easy to claim that a management regime is "sustainable" — and therefore acceptable — if the stock is not collapsing, ignoring the fact that just because the stock is stable does not mean that it is stable at an optimal level. Strait of Georgia chinook salmon are a case in point. The abundance of Strait of Georgia chinook has been relatively stable since the late 1980s, and this could be considered a management success. But if we take a longer view, we can see that the stock is stable at an abundance far, far below what it was before 1980, which could mean that productivity has fallen greatly or that escapements are far below what they should be.

A less common but probably wiser, more complex and costly approach is to use what biologists call "stock-recruitment analysis." This involves plotting productivity data against escapement data so as to clarify how much average productivity decreases when more fish are allowed to spawn. There are some difficult statistical problems with this type of data analysis — in particular it is likely to give a "biased" picture of productivity at low escapements (i.e. productivity can appear too high for low abundance situations). But statistical problems are now more clearly understood, and can be corrected in various ways. Fisheries and Oceans uses the formal stock-recruitment approach mainly for Fraser River sockeye and for a few coho "index" stocks where more accurate escapement and life-stage survival data have been gathered.

A major, coast-wide stock-recruitment assessment for all species was done in 1980 by Fred Wong, in an independent assessment for the Pearse Commission on Pacific Fisheries Policy. Further research could provide an improved basis for examining some tradeoffs that occur between overharvesting risks and compliance with the "precautionary approach" to fisheries management. With that research we should be able to say more precisely just how costly it might be (in short-term lost "production") to reduce harvest rates on some runs in favour of allowing higher, presumably safer escapement levels. The analysis could also provide a better basis for making reasonable projections about how many years it might take for some depressed stocks to rebuild, and about the long-term loss of fish production incurred by various habitat

changes.

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Coast-wide Stock Status and Trends, By Species

SALMON SPECIES

Chinook Salmon
Chum Salmon
Coho Salmon
Pink Salmon
Sockeye Salmon
Steelhead

Examination of broad trends in spawning abundance by species and region suggests that, with the exception of coho, the overall salmon situation in BC was relatively stable until the late 1980s. Many stocks have declined during the last ten years. The long-term overall catch has been highly variable but relatively consistent, until the last few years. The catches in the past five years are among the lowest in the last 50 years. The number of stocks contributing to catch has declined from many diverse stocks to only a few strong stocks. The abundance of stocks in broad areas is down. The number of stocks is down and many are at risk.

Some stocks are stable, others are in decline, and many are unknown. This indicates serious conservation difficulties that must be addressed.

In the following sections, we examine status trends for each species, review their key life history characteristics, as well as differences among stocks, and highlight conservation and management issues that may not be obvious from broad trend statistics.

Chinook salmon

Chinooks are the largest of the salmon species, sometimes reaching adult body sizes exceeding 40 kilograms. From a population ecology perspective, there are two types of chinook life histories that are so radically different that biologists sometimes wonder whether chinooks should be considered two separate taxonomic species.

The first type, "spring" or "summer" chinooks, spawn mainly in the upper reaches and tributaries of larger river systems. They enter the rivers in the spring or summer, then hold in freshwater for up to six months before they spawn in the fall. Their juveniles generally spend at least one year in freshwater. Their downstream migrating smolts are large, and these smolts tend to migrate rapidly northward after entering the sea. Most catches of spring-type chinook occur on BC's north coast and in Alaskan waters. Much of the

southern BC catch of spring-type chinooks comes from chinook originating in rivers in Washington and Oregon, especially the Columbia.

The second type, "fall" chinooks, generally spawn in lower-river tributaries. The Harrison River run, on the Lower Fraser, is (or was) one of the single largest chinook spawning runs in North America. Fall-type chinook juveniles go to sea in the spring after hatching, and spend only a few weeks or months in freshwater. These migrants tend to use estuarine rearing habitats as they go to sea, and do not move northward as rapidly or consistently as spring-type chinook. Some fall-type chinooks complete their ocean life quite near their natal streams — the sport and commercial troll fisheries for chinook in the Strait of Georgia have historically relied upon mainly fall-type fish, some from Puget Sound rivers, and some from rivers surrounding the Strait of Georgia. Unlike spring-type chinooks, fall-type chinooks spend an extra summer at sea, which makes them generally susceptible to much higher exploitation rates. Many fall-type chinook populations have been subject to exploitation rates at least twice as high (80 percent of potential spawners) as has been typical for spring type populations (often less than 40 percent of potential spawners).

Rebuilding of spring-type chinook runs has been something of a conservation success story. On the Fraser River, rebuilding efforts began in 1980 with the closure of early-season gillnet fisheries that targeted spring chinooks entering the river. Further ocean harvest restrictions, mainly in north coast and Alaska commercial troll fisheries, were introduced in the mid 1980s. These restrictions came after the Pacific Salmon Commission (the Canada-U.S. regulatory body established under the Pacific Salmon Treaty) began coast-wide assessments and highlighted spring-type chinook as a major international concern from the Columbia River northward. These restrictions have apparently also benefited central coast and north coast chinook stocks.

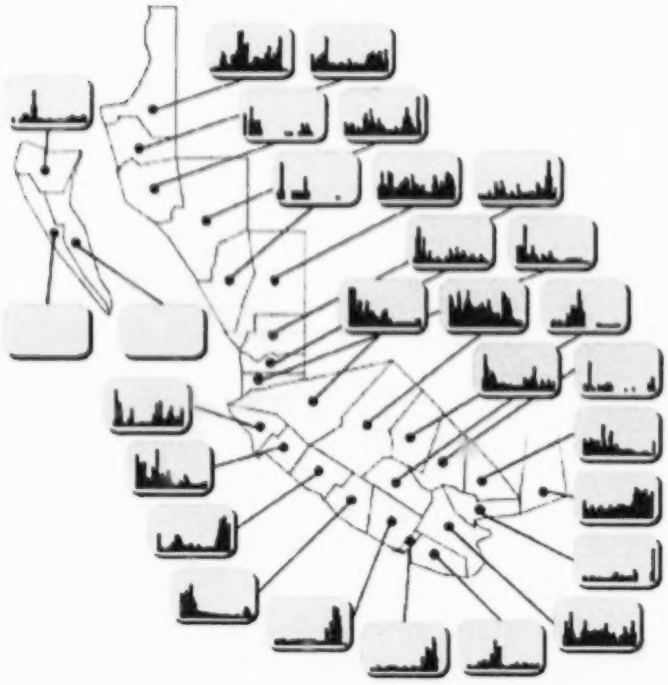
Chinook salmon have suffered from serious habitat degradation. In just one example, Nechako River chinook have been impacted by water withdrawals for power production in Alcan's Kemano project. There have also been worrisome declines in several spawning runs to the upper Fraser since the late 1980s, apparently caused by declines in marine survival rates that are thought to be impacting upon spring-type chinook from the Columbia River northward.

Overall, the spring chinook spawning runs are considerably healthier today than they were 20 years ago, but we still have a long way to go. The situation with fall chinooks from the south coast of BC is much more complex.

For fall chinook, there are contradictory signals in escapement monitoring compared to harvest and survival statistics. In the late 1970s, marine survival-rate estimates from fall chinook hatchery stocks around the Strait of Georgia and along the West Coast of Vancouver Island indicated that the hatchery populations, at least, had suffered a dramatic drop in survival. By the late 1970s, hatchery-reared chinook had come to account for about one-quarter of the Strait of Georgia sport and troll catch. In the early 1980s, there was a catastrophic decline in the Strait's sport and troll catches, resulting in the closure of the early-season commercial troll fishery, and by 1984, a complete closure of that fishery. Various restrictions were also imposed on the sport fishery, but evidence suggests that these restrictions were not effective at reducing exploitation rates. Today, the total "stock" of chinooks available to fishing in the Strait of Georgia appears to be radically smaller than it was before 1980 — in fact, over this 20-year period, the decline may be as much as 90 percent. Up to half of the fish now caught are hatchery-reared. Exploitation rates have declined in the

last few years as fishing-effort has declined, in tandem with fishing restrictions aimed at protecting coho salmon. These stocks haven't gone somewhere else because there has not been an increase in catches of chinook from Georgia Strait and Puget Sound rivers in "outside" areas (West Coast of Vancouver Island, north coast). Because of this, the absence of chinook in the Strait cannot be explained by any major change in ocean migration patterns. Further, concerns have been raised about the impacts of massive hatchery releases from both Puget Sound and Strait of Georgia facilities on wild stocks, as a result of competition in the limited waters of the Strait. Concerns have also been raised that hatchery releases attract fishing effort that adversely impacts upon wild chinook populations.

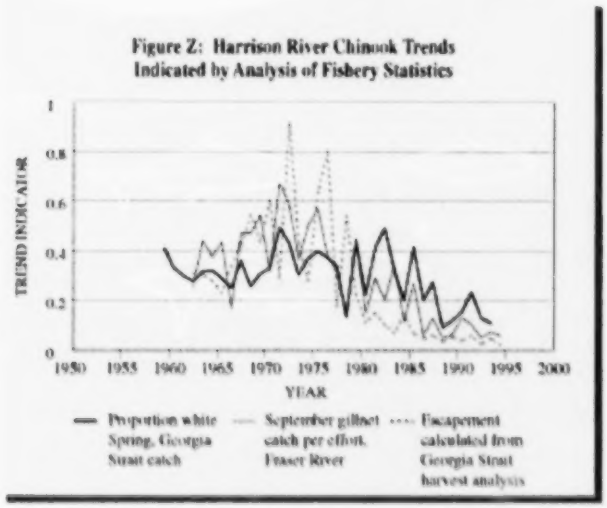
Trends in BC Chinook Salmon Escapements, 1950-97

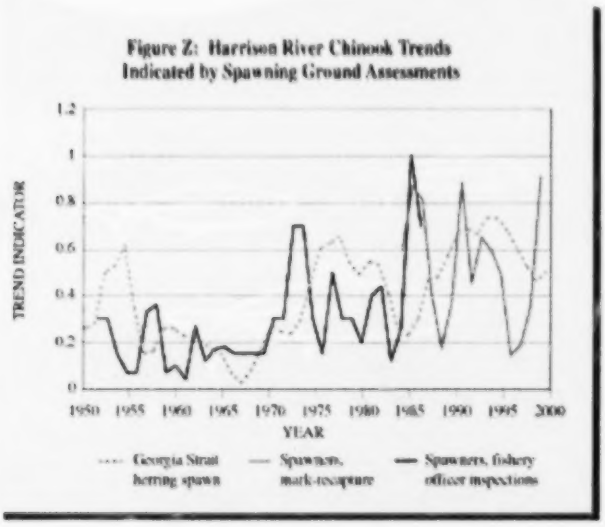


Most of the trend information is from DFO fishery officer inspections, summarized in the Salmon Escapement Data System (SEDS). Cautions to the reader: (1) SEDS information is incomplete; many smaller systems are not inspected regularly; (2) at least some apparent declines are due partly to reduced monitoring effort, especially after the mid 1980s; (3) some sudden increases are due to changes in monitoring methods, such as installation of fences and use of mark-recapture procedures on rivers where visual counting was impractical; (4) the trend pattern for each area is scaled to the maximum escapement recorded for that area; some areas have much higher total runs than others.

The numbers of chinook spawners for various stocks are shown by location of the inset graphs for the period 1950 (to the left) to 1997. The graphs have been scaled to a standard size so do not reflect relative stock sizes.

The summer chinook stocks, in the interior of BC, exhibit a pattern of building spawner abundance from left to right. The fall chinook stocks, on the coast, show the reverse pattern with high spawner abundance early, decreasing to the present. Hatchery stocks exhibit a different pattern of low abundance early in the period followed by a large increase when hatchery production came on line.





The Harrison River chinook salmon stock provides a good example of the troubles that ultimately arise from inadequate investment in escapement monitoring. Fishery statistics indicate the stock is in trouble (top panel), but escapement monitoring suggests it is healthy and may have responded to decline and recovery of herring abundance in the Georgia Strait (bottom panel). Both pictures could be completely misleading!

On the basis of catch and survival-rate statistics, it is reasonable to conclude that Georgia Strait and Puget Sound fall-type chinook stocks are in very deep trouble.

Something is very wrong with one of the most valuable salmon fisheries in BC. It should not be assumed

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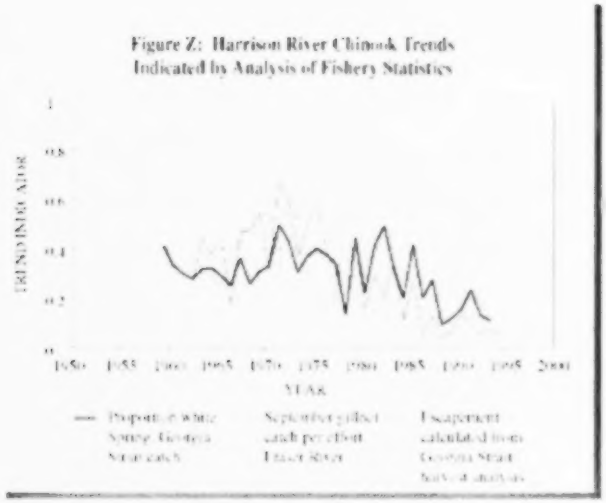

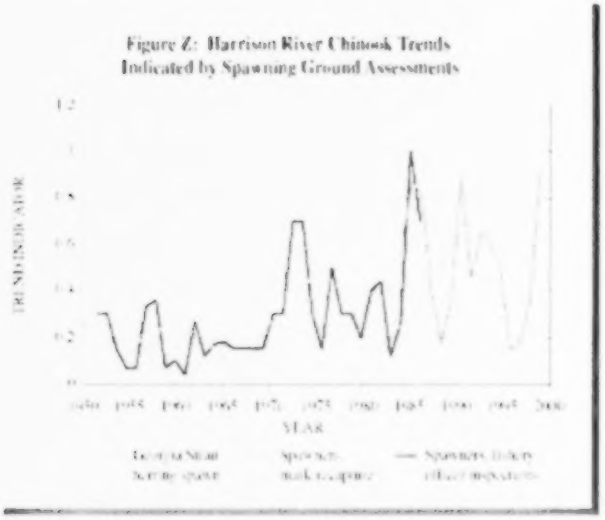

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Something is very wrong with one of the most valuable salmon fisheries in BC. It should not be assumed

that fisheries restrictions aimed initially at protecting coho salmon will also afford all of the protection required by chinook stocks. It is clearly time for a major reassessment of the state of fall-type chinook salmon from the Strait of Georgia and Puget Sound, and for constant cooperation with Washington State in analysis and policy development.

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Coast-wide Stock Status and Trends, By Species

Chum Salmon

SALMON SPECIES

Chinook Salmon

Chum Salmon

Coho Salmon

Pink Salmon

Sockeye Salmon

Steelhead

Chum salmon spawn in the lower reaches of most BC streams, where impacts like siltation from logging and dyking are greatest. As a result, chums are particularly sensitive to large-scale habitat damage, but they are remarkably "invasive," meaning they can quickly take advantage of new spawning opportunities created by accidental and deliberate habitat improvements. Juvenile chum go to sea within a few months after hatching. Like fall-type chinooks, chum salmon are likely to rear for a short time in estuarine areas. However, chum salmon undertake very extensive ocean migrations to the Gulf of Alaska, where they feed mainly on smaller plankton organisms and small fish, before returning to spawn at ages three to five years. Most chum spawning runs return later than other species (except coho), although "summer run" chums have provided valuable fisheries in the central coast and north coast areas.

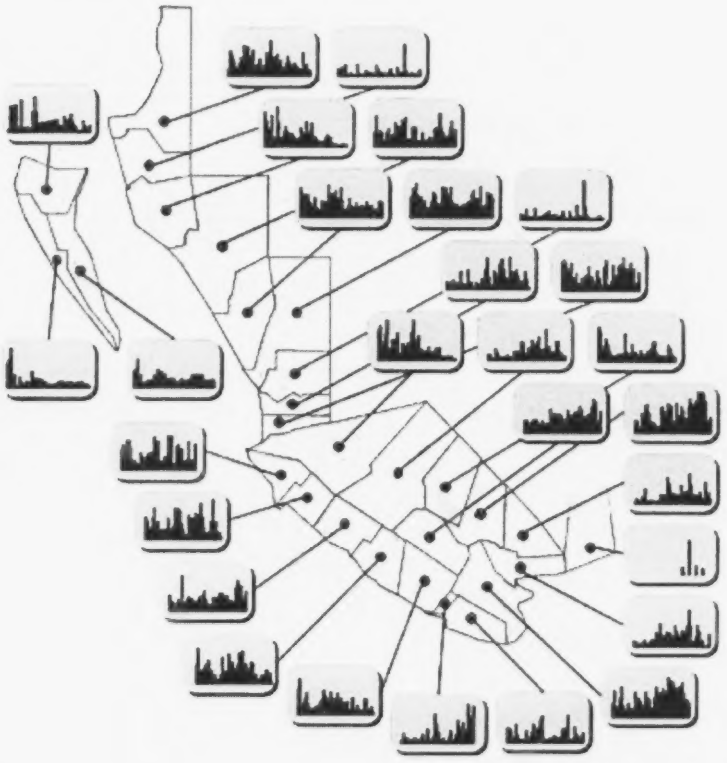
Until the 1970s, it was not known that chum salmon, on average, are much less productive than other salmon species. Most wild chum salmon populations are unable to withstand exploitation rates much higher than 20 to 30 percent (in contrast, a few sockeye stocks have been observed to increase even though they were being harvested at rates approaching 80 percent). During the 1950s and possibly the 1960s, there was extensive, coastwide overfishing of chum salmon runs, followed by various fisheries restrictions aimed at rebuilding the runs. Many chum runs, particularly those bound for smaller, remote coastal inlet areas, have not been subject to directed fishery openings for many years, although suspicions persist that many runs have been severely impacted by "creek robbing." This is a practice in which a high proportion of a chum stock is harvested by a single net, set on the fish when they gather at stream mouths immediately before entering the creeks to spawn.

In some areas, notably the Fraser River, fishing restrictions appear to have been successful in rebuilding chum populations, although rapid rebuilding does not occur because of the same low productivity that makes it necessary to limit exploitation rates.

Chum salmon have been a favorite target for salmonid enhancement because they respond so dramatically to simple hatchery systems and spawning channels. There is little evidence that hatchery production systems

interfere with nearby wild populations, either by competition with wild stocks, or by attracting fishing effort that may impact upon wild stocks. Unlike hatchery coho and chinook stocks, which are harvested mainly in mixed-stock fisheries, hatchery chum (and pink) are often harvested in very localized "terminal fisheries."

Trends in BC Chum Salmon Escapements, 1950-97



Most of the trend information is from DFO fishery officer inspections, summarized in the Salmon Escapement Data System (SEDS). Cautions to the reader: (1) SEDS information is incomplete; many smaller systems are not inspected regularly; (2) at least some apparent declines are due partly to reduced monitoring effort, especially after the mid 1980s; (3) some sudden increases are due to changes in monitoring methods, such as installation of fences and use of mark-recapture procedures on rivers where visual counting was impractical; (4) the trend pattern for each area is scaled to the maximum escapement recorded for that area; some areas have much higher total runs than others.

The numbers of chum spawners for various stocks are shown by location of the inset graphs for the period 1950 (to the left) to 1997. The graphs have been scaled to a standard size so do not reflect relative stock sizes.

Chums show highly variable returns within and between stocks. Some stocks on the inner south coast have increased production as a result of a long-term rebuilding strategy. Some other stocks have been relatively

stable and others have declined.

There are two regions of some conservation concern for chum salmon, where escapement data indicate considerable declines since 1950. In the Queen Charlotte Islands, chum spawner abundance statistics show a sudden decline in the early 1950s and have not recovered since. In the southern part of the Central Coast and Johnstone Strait, there has been a long-term pattern of decline. Some of these runs have likely been decimated by directed fisheries.

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Coast-wide Stock Status and Trends, By Species

Coho Salmon

SALMON SPECIES

Chinook Salmon
Chum Salmon
Coho Salmon
Pink Salmon
Sockeye Salmon
Steelhead

This section provides only a general overview about coho population biology, coast-wide stock trends, and reasons for general concern about the species. In particular, we point out here that in fact, the coho "crisis" has been, and will likely continue to be, a long-term problem.

Coho find their way into an amazing number of small spawning streams in BC, ascending to spawn even in tiny tributaries less than a metre wide and ten to 20 centimeters deep. Like chum, they can be aggressive colonizers when favourable habitat is created or restored. As fry in their first spring of life, coho disperse widely through their natal watersheds. Most then spend just one winter in freshwater where they seek protected, relatively deep pools and backwaters, then head to sea the following spring. Some juveniles, especially in streams with poor growth conditions, hold over for a second freshwater year. A few "jack" males return after just one summer at sea; most females spawn on their third birthday.

Though juvenile BC coho have been captured as far north as the Aleutian Islands, most fish do not move far from their natal streams. For example, most Strait of Georgia coho are caught in the Strait, or recently, on the west coast of Vancouver Island and along the central coast. In the past, apparently only about ten to 20 percent of the fish left the Strait, although 90 percent or more have "outmigrated" in most years since 1990. This raises suspicions of major changes in the Strait of Georgia environment.

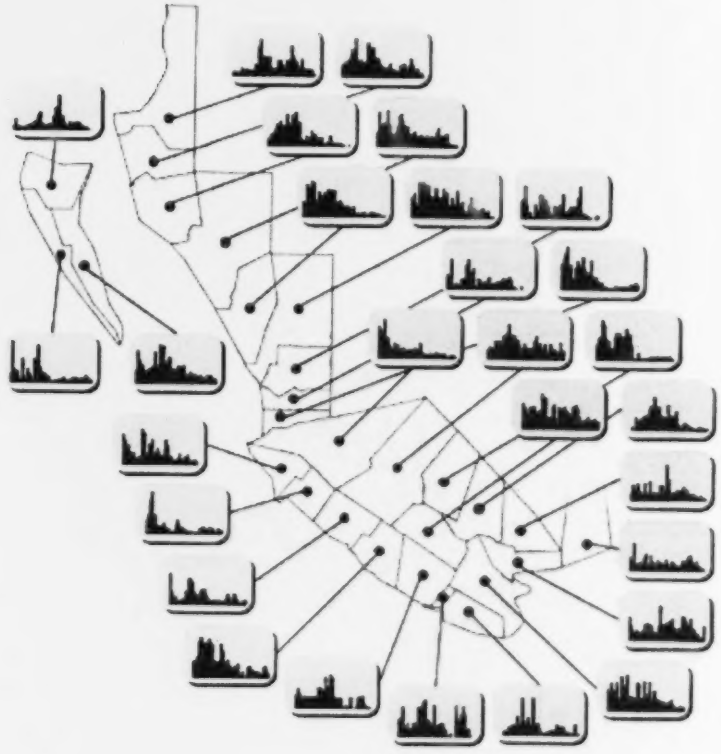
There is much concern publicly expressed that herring roe fisheries in the Strait of Georgia may be depleting a key food source for coho salmon. There is sharply divergent opinion on this issue. The debate is far from settled and needs further careful consideration.

Like chinook, coho are impacted by fisheries throughout their ocean life. They are "shaken" by sports and troll fishermen and "squished" by seine fishers during their first ocean summer. They are hit again by sports and troll fishermen through the following spring and summer. They are taken in seine and gillnet fisheries as they migrate back into coastal rivers, where they are finally pursued by sports and Aboriginal fishermen. Historically, the cumulative effect of this gauntlet has been to exert total exploitation rates sometimes

exceeding 80 percent on the potential spawners. With harvest mortality rates this high, it is remarkable that coho populations have not declined even more rapidly over the years.

Coho are not the only species to have suffered severe declines in marine survival rates since the mid-1980s. Similar trends have been observed in steelhead populations from Oregon through BC, in many spring-type chinook salmon from interior streams, and even in Atlantic salmon stocks off eastern Canada. There is scientific concern that these very large-scale correlations may not be accidental, and that there may in fact be something going very badly wrong with freshwater or coastal rearing habitats throughout North America. One suggestion has been that a change in ocean conditions in the late 1980s may be partly responsible. Since these declines in survival rates have been observed mainly in species that rear in freshwater for a year, it has been suggested that some factor like ultraviolet radiation is impacting the fish while they are in freshwater. The implication is that this impact does not kill them immediately, but instead makes them vulnerable to mortality during the stressful period of early ocean life.

Trends in BC Coho Salmon Escapements, 1950-97



Most of the trend information is from DFO fishery officer inspections, summarized in the Salmon Escapement Data System (SEDS). Cautions to the reader: (1) SEDS information is incomplete; many smaller systems are not inspected regularly; (2) at least some apparent declines are due partly to reduced monitoring effort, especially after the mid 1980s; (3) some sudden increases are due to changes in monitoring methods, such

as installation of fences and use of mark-recapture procedures on rivers where visual counting was impractical; (4) the trend pattern for each area is scaled to the maximum escapement recorded for that area; some areas have much higher total runs than others.

The numbers of coho spawners for various stocks are shown by location of the inset graphs for the period 1950 (to the left) to 1997. The graphs have been scaled to a standard size so do not reflect relative stock sizes.

All stocks show a decline in spawner abundance in recent years. The interior stocks dropped very significantly. Most coastal stocks dropped less, but significantly. Hatchery stocks have dropped the least.

When we examine long-term escapement trends, it is obvious that coho salmon in BC have been in trouble for a long time. The trouble has not been isolated to coho salmon from just a few interior Fraser and Skeena streams. The trouble did not begin with the alarming declines in marine survival rates that began in the late 1980s. Escapement data strongly indicates a chronic, long-term problem, of declining productivity and/or the result of overfishing. Indeed, if we analyze the data in conjunction with estimates of average exploitation rates since 1950, stock-recruitment methods indicate that most coho stocks should probably never be subject to exploitation rates exceeding 50 percent. Historical exploitation rates, in contrast, have averaged between 60 percent and 80 percent for most stocks. Under current marine survival conditions, there are some stocks that can sustain no exploitation rate whatsoever. In other words, we are not just dealing with a short-term survival problem that will soon correct itself so that fishing can go back to "normal." Many coho stocks will probably never be able to withstand the harvesting rates, and habitat changes, that have driven them down steadily for the past 40 years.

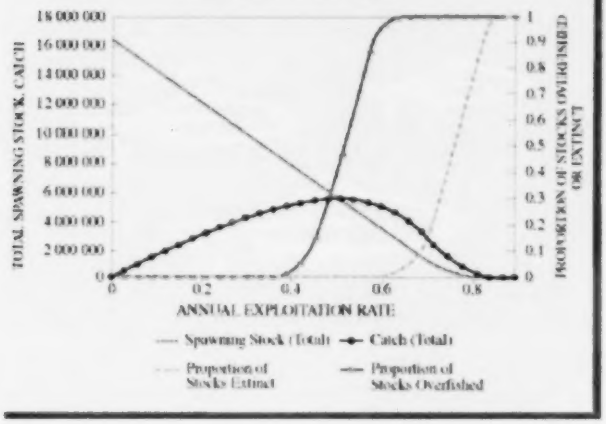
Biologists were talking seriously about a coho "problem" by the early 1980s, when accelerating declines in interior escapement numbers started to make it plainly obvious that for some runs, at least, the situation was becoming critical. However, not all biologists accepted the information as being soundly based, for the following reasons:

1. Data for most coho spawning streams could not be trusted (coho are notoriously difficult to see and count in small streams);
2. Catches showed no trend despite escapement declines, at least in part due to increasing hatchery production (to 50 percent of the total Strait of Georgia catch by the mid 1980s, for example);
3. Declines could be blamed on habitat alteration, in spite of how the declines were occurring over virtually all streams, disturbed or not; and, perhaps most significantly,
4. Detailed study of a few index stream coho populations did not show an "overfishing" problem — the index populations produced similar smolt outputs, based on counts of downstream migrant juveniles, whether or not there had been few or many parental spawners.

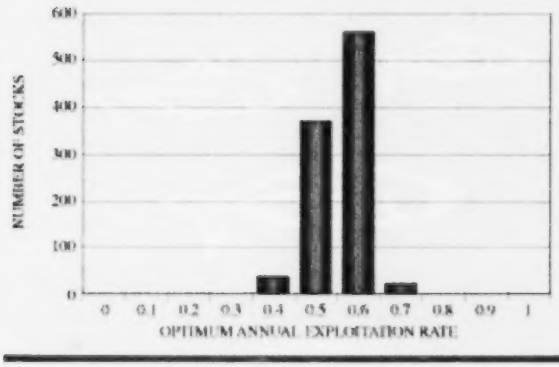
The index stream population studies, on streams like Carnation Creek and Black Creek on Vancouver Island, may have been, at least to some extent, misleading. These studies have provided fascinating insights about how salmon are produced, and in particular about the processes of "compensatory mortality" that cause productivity-per-spawner to increase when there are fewer spawning fish, and which also limit the number of recruits produced when spawner numbers are high. When spawner numbers are low, a high percentage of

the eggs survive to the smolt stage; when spawner numbers are high, juvenile mortality rates increase sharply so that only a limited number of juveniles survive to the smolt stage, indicating that there is severe competition among juveniles for space, food, etc. within rearing streams. These index streams were chosen in the first place because they had reasonable numbers of fish for study and were not obviously collapsing. It now appears that these index streams, upon which various analyses of sustainable harvest rate have been based, may be near the upper range of coho productivity. They may have been good sites for monitoring escapement declines and changes in marine survival rates and exploitation rates, but they were also maintaining smolt production despite a general decline in coho abundance elsewhere. Estimates of "optimum" sustainable exploitation rates for the index populations average around 60-70 percent, whereas analysis of data from all the stocks suggest a rate about 20 percent lower.

Figure Y: Effect of Increasing Coastwide Exploitation Rate on B.C. Coho Stocks



Frequencies of Optimum Exploitation Rates over B.C. Coho Stocks



Coho stocks vary widely in productivity, as indicated by the number of stocks having different "optimum exploitation rate" (proportion of recruits that should be harvested annually in order to produce highest average catch over the long-term). As coastwide exploitation rate increases, the proportion of stocks that are at risk to overfishing and extinction increases.

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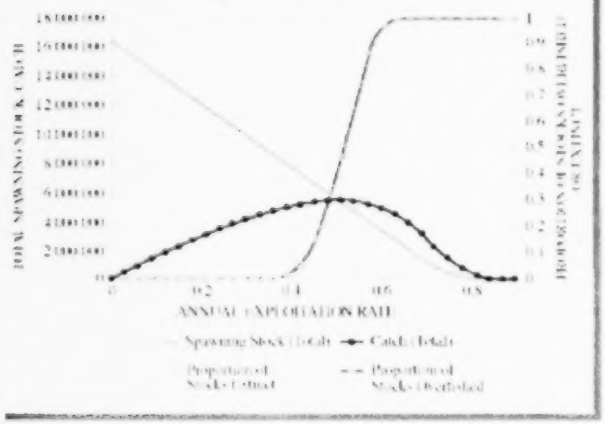
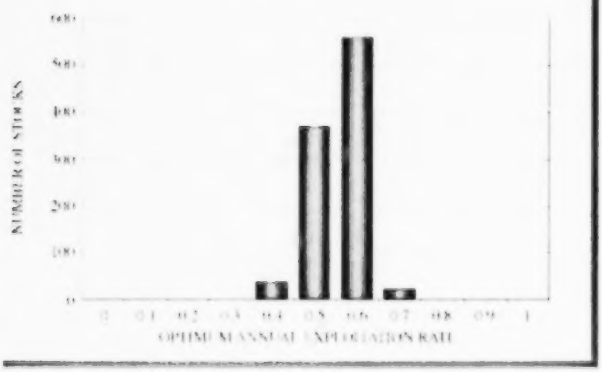
Figure 9: Effect of Increasing Coastwide Exploitation Rate on B.C. Coho Stocks



Frequencies of Optimum Exploitation Rates over B.C. Coho Stocks



Coho stocks vary widely in productivity, as indicated by the number of stocks having different "optimum exploitation rate" (proportion of recruits that should be harvested annually in order to produce highest average catch over the long-term). As coastwide exploitation rate increases, the proportion of stocks that are at risk to overfishing and extinction increases.

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Coast-wide Stock Status and Trends, By Species

Pink Salmon

SALMON SPECIES

Chinook Salmon
Chum Salmon
Coho Salmon
Pink Salmon
Sockeye Salmon
Steelhead

Like chum, pink salmon spawn mainly in the lower reaches of coastal rivers, and juveniles go to sea the next spring soon after hatching. Unlike chum and fall chinook, which often rely upon estuaries, pink salmon immediately begin to move northward after entering the ocean, reaching ocean feeding areas in the Gulf of Alaska by the winter of their first ocean year. They then spend a second summer at sea, and almost all individuals return to spawn on their second birthday. A few are taken by sport fishers during the return migration, but most of the harvest is by large commercial seine and gillnet fisheries, deployed on migration approach routes and at river mouths.

Like chum and coho, pink salmon can be highly invasive, aggressively colonizing new habitat opportunities. As an example, pink salmon were rendered virtually absent from the middle sections of the Fraser River, following the Hell's Gate disaster of 1913. However, by 1948, fisheries officers started to see them again in tributaries of the Thompson River. That upriver "population" expanded over the next 20 years, so that now there can be several million fish spawning upstream from Hell's Gate.

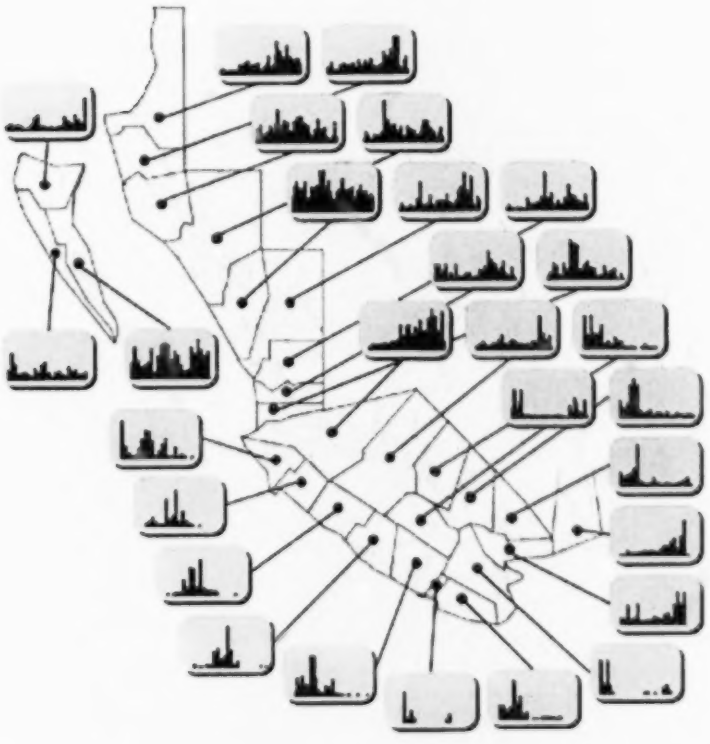
North of Campbell River, most coastal streams have both "cycle lines" of pinks (both even-year and odd-year spawning runs). South of Campbell River, only the odd-year cycle line is abundant, so there is a pink fishery only every other year. On the west coast of Vancouver Island, only the even-year line has been seen in any numbers since 1950. There are both even and odd cycle lines of most pink populations along the coast north of Vancouver Island and of those, there have been occasional years of very poor marine survival, most notably a few very recent years. However, the long-term records indicate that pink salmon are quite capable of recovering rapidly.

It appears that there are three major areas of conservation concern for pink salmon -- the Strait of Georgia/Johnstone Strait, Vancouver Island's west coast, and the Queen Charlotte Islands. The Strait of Georgia/Johnstone Strait situation involves a classic "mixed stock" harvest management regime. Pink salmon returning to the Fraser River "co-migrate" with pinks returning to other streams around the Straits. The pre-harvest Fraser River run has averaged eight million or more fish in recent years, which is often ten times the

number of pink salmon bound for all the other streams around the Strait. Furthermore, the Fraser fish appear to be able to withstand considerably higher harvest rates. It has apparently been a management policy with the "entrance net fisheries" (Johnstone Strait, Juan de Fuca) to set exploitation rate and escapement goals with the dominant Fraser runs in mind, allowing the other runs to decline.

Pink data from south of Cape Cook on the west coast of Vancouver Island are difficult to interpret. Fisheries inspectors recorded no pinks there before 1954. Then there was apparently an "invasion" that led to fish being seen in 60 streams, and peak numbers totaling perhaps 200,000 spawners by 1972. Then escapements crashed, and pink have not been reported since 1982. Such "spasmodic" population patterns are not uncommon in fish population biology, and they can arise in at least two ways: (1) habitats may be unsuitable for a species most of the time, but allow occasional colonization and ephemeral population development; or (2) there was early, severe overfishing before 1950, followed by recolonization and another bout of overfishing in response to renewed opportunity.

Trends in BC Pink Salmon Escapements, 1950-97



Most of the trend information is from DFO fishery officer inspections, summarized in the Salmon Escapement Data System (SEDS). Cautions to the reader: (1) SEDS information is incomplete; many smaller systems are not inspected regularly; (2) at least some apparent declines are due partly to reduced monitoring effort, especially after the mid 1980s; (3) some sudden increases are due to changes in monitoring methods, such

as installation of fences and use of mark-recapture procedures on rivers where visual counting was impractical; (4) the trend pattern for each area is scaled to the maximum escapement recorded for that area; some areas have much higher total runs than others.

The numbers of pink spawners for various stocks are shown by location of the inset graphs for the period 1950 (to the left) to 1997. The graphs have been scaled to a standard size so do not reflect relative stock sizes.

Southern stocks return on odd years only. Most southern stocks, except the Fraser, have declined significantly. Most northern stocks return on both even and odd years. The abundance of even and odd cycle returns has varied but most northern stocks have not declined significantly until the last few years. Although the Queen Charlotte Islands stocks have even and odd year returns, the odd year returns have recently been very small.

In the Queen Charlotte Islands, "odd year" pink spawning populations appear stable, but "even year" populations are very low. It is unclear why one cycle line should prosper while the other does not.

Studies of pink salmon populations in northern BC (Sashin Creek) and Alaska have shown a population response effect called "depensation" — at very low spawning abundances, there can be severe depression in juvenile survival rates, apparently due to most fry being eaten by predators (not enough fry outmigrating to "swamp" predators, such as coho smolts or trout). Such depensatory effects can hinder or delay recolonization after a natural disaster or overfishing, and also cause extinctions after even relatively short periods of overfishing.

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Coast-wide Stock Status and Trends, By Species

Sockeye Salmon

SALMON SPECIES

Chinook Salmon

Chum Salmon

Coho Salmon

Pink Salmon

Sockeye Salmon

Steelhead

Sockeye salmon is the bread and butter species of BC's commercial salmon fishery. It has been harvested commercially, and managed to at least some degree, for over a century. As noted previously, sockeye runs have been monitored more closely than any other species.

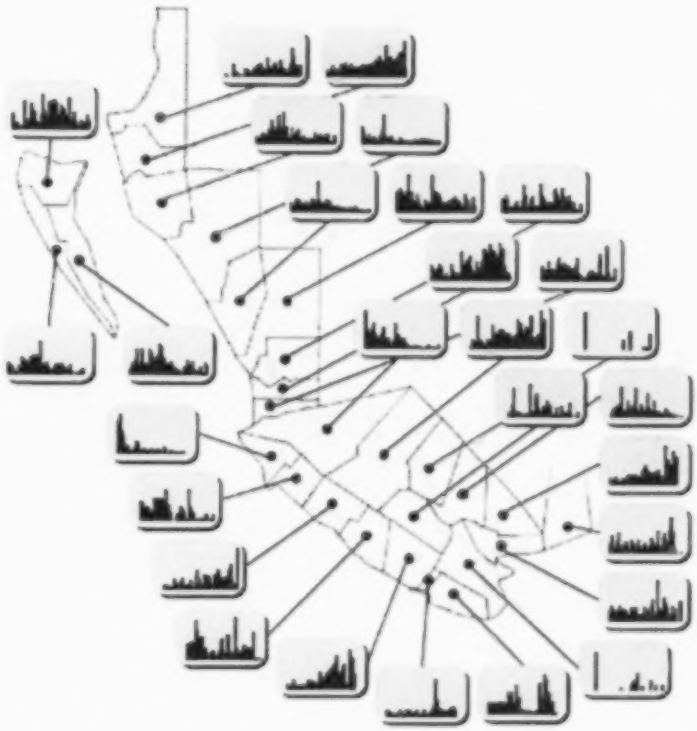
Sockeye salmon spawn in tributaries and shoreline areas around many large BC lakes. The following spring, fry then move into the rearing lake, and spend a year or two years there before going to sea. Like pink salmon, juveniles migrate rapidly northward to reach rearing areas in the Gulf of Alaska by the fall or winter of their first ocean year. Typically, sockeye spend two summers at sea, returning to the coast any time from early-July (as is the case with Skeena River sockeye, Rivers Inlet sockeye, and the Early Stuart run in Fraser River) to late September (as is the case with sockeye bound for the Adams River, in the Fraser River). Fish that rear in productive interior lakes, such as Stuart, Horsefly, and Shuswap, enjoy good juvenile growth rates. They go to sea at a relatively large size, enjoy a relatively good marine survival rate, and return to spawn mainly on their fourth birthday. Fish that rear in less productive lakes, such as Chilko, most coastal lakes from Vancouver Island and the central coast, and Babine Lake in the Skeena system) go to sea when they are much smaller. They also have lower marine survival rates, generally, and return to spawn on a mixture of fourth and fifth birthdays.

Very broadly, sockeye salmon management can be viewed as quite a success story on some large stocks, particularly if we focus only on the sockeye runs and ignore other species and stocks that have been impacted by the fisheries that target sockeye. Following bouts of overfishing, and disasters such as the Hell's Gate slide in the Fraser and the Babine slide in the Skeena system, most larger stocks have been substantially rebuilt. In some cases, sockeye have recolonized spawning areas that were barren of fish 80 years ago. Sockeye harvest management systems for major areas (Skeena, Rivers/Smith Inlets, Barkley Sound, Fraser) involve relatively sophisticated in-season information-gathering and adjustment of fisheries so as to improve the odds of meeting exploitation-rate and escapement targets. Accidental overfishing events are relatively rare. Innovative approaches to management are being tested on the relatively small Nass River run, where biologists and Aboriginal communities are working together to develop harvesting methods that combine high selectivity and "fishing for information," in which part of the catch is tagged and

released for later estimation of spawning run sizes. By observing production from wide ranges of spawning abundances, information now exists about the "optimum" number of spawners needed to produce high and apparently sustainable harvests for some major spawning runs.

However, considerable conservation problems exist in each of the main sockeye fisheries, beyond those created by incidental capture of other species. These problems range from mixed-stock impacts in the Skeena to difficulties with the regulation of the complex gauntlet of fisheries that take Fraser River fish.

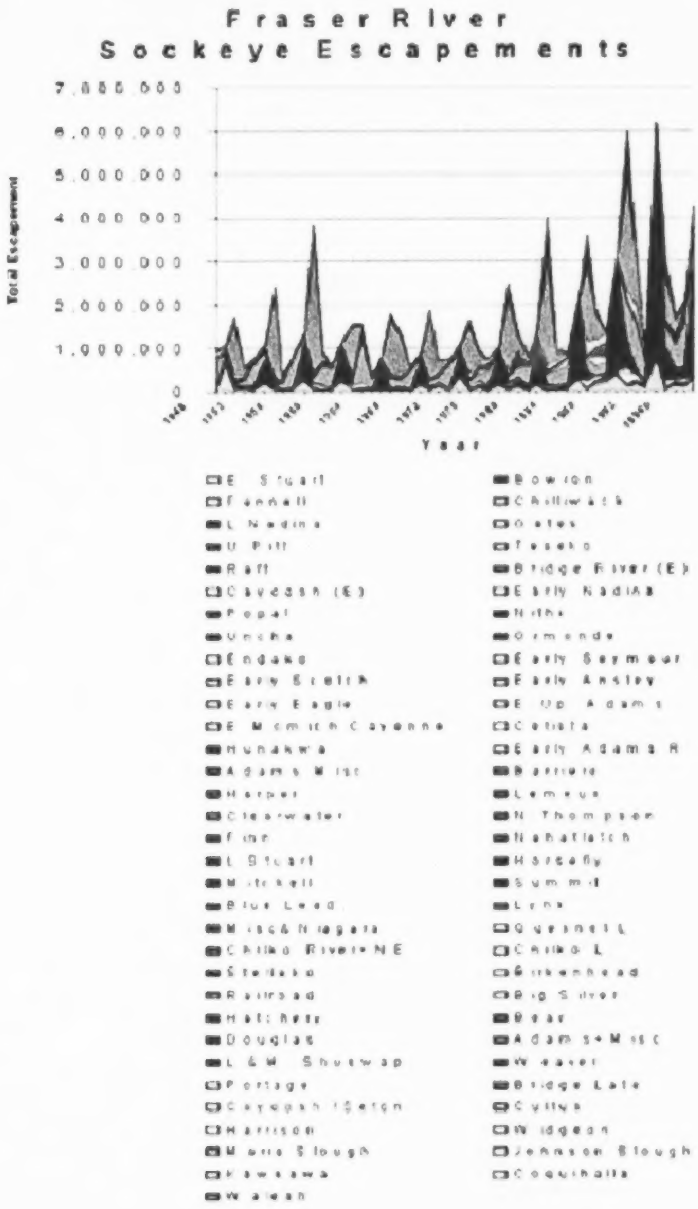
Trends in BC Sockeye Salmon Escapements, 1950-97



Most of the trend information is from DFO fishery officer inspections, summarized in the Salmon Escapement Data System (SEDS). Cautions to the reader: (1) SEDS information is incomplete; many smaller systems are not inspected regularly; (2) at least some apparent declines are due partly to reduced monitoring effort, especially after the mid 1980s; (3) some sudden increases are due to changes in monitoring methods, such as installation of fences and use of mark-recapture procedures on rivers where visual counting was impractical; (4) the trend pattern for each area is scaled to the maximum escapement recorded for that area; some areas have much higher total runs than others.

The numbers of sockeye spawners for various stocks are shown by location of the inset graphs for the period 1950 (to the left) to 1997. The graphs have been scaled to a standard size so do not reflect relative stock sizes.

Sockeye stocks such as Babine and Somass that are enhanced, and some Fraser stocks, have increased over the period. Others such as Rivers and Smith Inlets, Bella Coola, Nimpkish and smaller coastal stocks have declined.



The 1948 to present escapement for the 65 Fraser sockeye stocks show cyclic returns with some stocks building dramatically and others much less.

In the 1960s, spawning channels were established on the Fulton and Pinkut Rivers on Babine Lake, establishing highly-productive sockeye subpopulations in the Skeena system. These subpopulations were established in the midst of a complex of less-productive, wild spawning runs to lake shorelines and the other

Babine and Skeena tributaries. Recognizing the risk to other stocks, Fisheries and Oceans managers initially limited the exploitation rate of the Skeena-mouth fisheries to about 60 percent, which is close to what it had been before the "enhancement" of the Fulton and Pinkut rivers. Under this regime, there was some initial decline in wild stocks, possibly related to competition in Babine Lake with the abundant fish from the enhanced stocks. Most runs, however, had stabilized by the mid-1980s.

Since 1990, however, there have been two very worrisome changes. First, there has been an upward trend in exploitation rates, which exceeded 70 percent in 1996 and 1997. It is doubtful that the wild stocks can be sustained at these rates of exploitation. Second, there has been a substantial decline in both egg-to-fry and fry-to-smolt survival rates. The decline in fry-to-smolt (lake rearing stage) survivals is especially worrisome, since it may represent an effect of long-term "overstocking" of Babine Lake with juveniles. Smolt production has fallen to pre-enhancement levels, and this will likely impact wild spawning runs far harder than the enhanced runs. Outside the Babine, the majority of spawning runs to other Skeena River lakes (e.g. Bear Lake, Swan Lake) have apparently not even been inspected in recent years.

The central coast area once supported the second largest sockeye fishery in BC, after the Fraser. The central coast fisheries, at Rivers Inlet and Smith Inlet, are now essentially closed. Since 1990, total returns to both systems have fallen dramatically and are well below escapement goals determined from historical spawning and recruitment data. The magnitude of the problem suggests that the causes of this decline should be investigated. This is an example of the "shifting baseline syndrome." Recent studies of juvenile size and abundance suggest that the main current problem is a major decline in marine survival rate. These stock data were collected well after the catches had declined significantly. It is unclear what caused the earlier decreases.

In the Fraser system, a potential management problem of too many fish has been suggested. A dramatic pattern is displayed by a few Fraser River stocks, mostly by those using productive lakes and returning mainly at their fourth birthday (Late Stuart, Horsefly, Adams River stocks). That pattern is called "cyclic dominance," and involves a dramatic four-year cycle in abundance: large spawning runs, or "cycle lines" produce large recruitments, a subsequent "subdominant" line produces somewhat smaller recruitments, and two "off-cycle" lines, with very few spawners. The difference between the dominant lines and the off-cycle lines can be remarkable, ranging from millions of returning fish in the dominant year to a few thousand fish in the off-cycle year. There are also major differences in production rates between lines.

From the late 1930s to the mid 1980s, the International Pacific Salmon Fisheries Commission (IPSFC) largely controlled Fraser River sockeye management. During that period, it was apparently assumed that the cyclic-dominance pattern was a natural, even necessary pattern. It was thought that dominant cycle lines might stimulate predator populations or deplete lake food resources such that the lakes could produce only one or two large runs out of four. For a time, an active program was established to ensure continuation of the pattern (for example, many fish from a large sub-dominant return to the Adams River, in 1971, were deliberately prevented from spawning). Analyses of spawning-recruitment data during the mid-1980s called this assumption into question. It was pointed out that statistical methods used by IPSFC staff to estimate productivity of non-dominant lines, and to estimate between-line "interaction effects," may have led to gross underestimates of optimum spawning numbers for these lines. Revised statistical procedures suggested that the non-dominant lines should be rebuilt. The argument for rebuilding was supported by evidence that spawning runs had historically been much larger than would be predicted from the IPSFC assessments.

In the late 1980s, biologists strongly recommended an experimental stock rebuilding program for "off-cycle" spawning runs from the stocks that showed cyclic dominance. This rebuilding program was never intended to apply to the dominant cycle lines for which there was historical evidence that more spawners would not likely result in improved recruitment. There was some discussion about how increasing spawning numbers for dominant lines might stimulate dispersal of fish to recolonize historical spawning sites, but this possibility was recognized to be a long-shot gamble that should not take precedence over experimental rebuilding of off-cycle lines.

Over the years, these recommended experiments have apparently been modified by DFO. Very high escapement targets have been set for dominant cycle lines as well as the off-cycle lines. Some historical data indicates that increased escapements of dominant cycle line fish are unlikely to result in higher recruitments. Also, fully harvesting highly productive dominant cycles would result in over-harvesting other off-cycle and rebuilding runs. From a fishing industry perspective, high dominant cycle escapements amount to "overspawning." They see the fish as "wasted" because they are unlikely to result in higher future returns and catches, and in some cases might result in declines in production. This is an important issue that should be addressed.

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Steelhead Salmon

SALMON SPECIES

Chinook Salmon
Chum Salmon
Coho Salmon
Pink Salmon
Sockeye Salmon
Steelhead

Steelhead salmon are an anadromous form of rainbow trout that generally spawn and rear in medium-sized streams in coastal and interior BC. Unlike Pacific salmon, a small percentage of spawning fish remain alive after mating, return to sea, and return to spawn in subsequent years. As many as five repeat spawning events for rare individuals have been recorded.

Steelhead can be divided into three groups based on adult return timing — winter-run stocks, coastal stocks, and interior stocks. Winter-run stocks typically enter coastal rivers between November and April. Coastal summer-run fish typically enter rivers in the late winter to early spring and spawn in the same year. Interior summer-run stocks enter freshwater in the summer and autumn, and spawn the following spring. Juveniles spend from one to four winters in freshwater before emigrating to sea as smolts in the spring. Steelhead spawning in southerly rivers, with warmer water temperatures, typically have shorter freshwater rearing periods compared to steelhead from northern rivers. Adults spend one to three years in the ocean before returning to spawn.

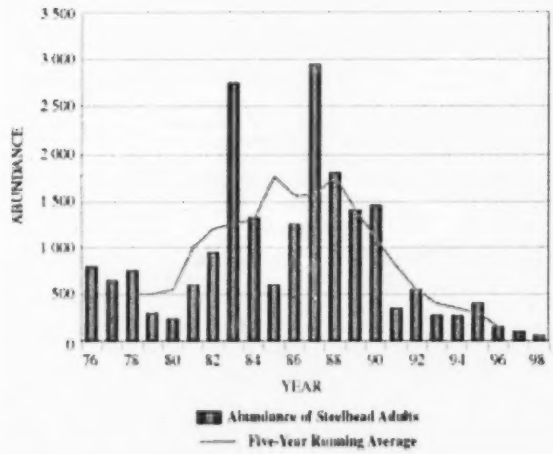
Steelhead are a prized recreational species throughout British Columbia. As of 1989, provincial angling regulations require catch-and-release of all wild steelhead in most of the province. Hooking mortality is generally considered to be low (less than ten percent). Bait-bans and the use of single barbless hooks in rivers with depressed steelhead populations are used to minimize hooking mortality. There is no commercial fishery targeted directly at steelhead, although steelhead are intercepted as a by-catch in net fisheries along migratory corridors in marine and fresh waters. Winter-run stocks typically have low interception rates because they return to spawn during times when most commercial salmon fisheries are closed. The largest proportion of steelhead intercepted are interior summer stocks of the Fraser and Skeena Rivers — their run-timing overlaps with sockeye, pink and chum salmon net fisheries in early summer to early fall.

Assessment of steelhead stocks by fisheries agencies is generally poor, for a number of reasons. Steelhead have been managed by the provincial government (BC Ministry of Fisheries and BC Ministry of Environment, Lands, and Parks) which has a very small stock assessment budget. In addition, spawning runs of steelhead

are generally low in total numbers, occur over a much longer period (November to May) relative to Pacific salmon, and for many runs, the peak timing is in the spring, during periods of high discharge and turbidity. These factors increase the cost and reduce the feasibility of relying on fish-counting weirs to obtain reliable escapement estimates. There are a few counting fences that enumerate steelhead in the province (Keogh River, Vancouver Island; Sustut River and Toboggan Creek in the Skeena), but for the most part, stock assessment relies on surveying juvenile densities and snorkel counts of adults. There is also a recreational-catch statistics database extending back to 1968 that can be used to provide a relative index of abundance in different rivers. These catch data must be interpreted cautiously: Changes in angling regulations, response rates to the angling questionnaire, and other factors introduce considerable error into catch-based assessments. However recent studies suggest that these catch-based assessments may be reliable for assessing regional trends over time.

Figure X: Steelhead

Abundance of steelhead adults (bars) in the Keogh River, BC, from 1976 to 1998, and the five-year running average (line). Reproduced from Ward (1999).



The fish-counting fence on the Keogh River, on Vancouver Island's east coast, provides the longest (23 years) and most reliable information on adult escapement and smolt run size for any steelhead stock in the province. Adult returns, which averaged 1,168 fish from 1976 to 1990, were significantly lower (187 fish) during the period 1991 to 1997. Only 40 wild females returned to the 35-kilometer river during the winter of 1995/96. Only 20 returned in 1996/97, and half that number returned in 1997/98. This winter-run stock and steelhead runs to several other rivers in the area — such as Cowichan, Puntledge, French, Quatse — are at very low numbers. Provincial biologists consider these runs to be at high risk of extinction.

Smolt-to-adult survival rates for Keogh River steelhead have been estimated to average 15.5 percent from 1976 to 1989, but survival rates between 1990 and 1995 are believed to have dropped to 3.8 percent. Studies indicate that trends in steelhead abundance for populations from throughout Vancouver Island's east coast, and the BC central coast, are well-matched to the disturbing trends in the marine survival rates of Keogh River steelhead smolts. If declining trends in marine survival continue, many of these stocks may become extinct.

In contrast, the few steelhead index streams on Vancouver Island's west coast exhibited exceptionally high escapements in 1998, in excess of four to five times the target escapements. These good returns were attributed to a reduction in the commercial fishery interception rate due to the coho-related fishery closures of 1998.

There are steelhead conservation concerns for Fraser River stocks. The Fraser River has at least 21 streams located in the lower river that support winter run stocks. Escapement data for these stocks is limited since they are generally small and the streams are difficult to survey. Escapement to these streams is highly variable over time, however the overall escapement for this stock group has declined significantly over the past decade, especially for the early-timed component of the run. Summer run stocks can be divided into coastal and interior groupings. Only three tributaries of the Fraser River support summer run coastal stocks (Coquihalla, Chehalis, Silverhope). The Coquihalla stock is relatively well monitored and run size has declined over the past two decades largely due to habitat related impacts resulting from road construction and mining activities. Interior summer run fish include those migrating to the Thompson River and its tributaries, the Chicoltin River system, and other tributaries entering on the west side of the Fraser River (Bridge, Seton, Stein, Nahatlatch). B.C. Ministry of Fisheries target escapements required to fully seed available habitat in the Thompson have not been realized over the past two decades. The target escapement to the Chilcotin system has only been achieved once since the early 1970s. There is little escapement data to comment on stock status of west-side tributaries.

There are also steelhead conservation concerns in other areas of the province. Steelhead runs to the Bella Coola and Atnarko Rivers are depressed, relative to historical levels. The average annual return for the 1991-95 period was only a third of the average for the previous five years. Some stocks in the Lower Mainland and Howe Sound area, such as the Squamish River winter run, have been listed by provincial biologists as scarce and at moderate risk of extinction, based on very noticeable declines in angling catch. There is also concern for summer-run Skeena River stocks that are intercepted in net fisheries that target sockeye salmon. Run sizes, indexed by a test fishery, showed progressive declines, and total escapement to the Skeena system has generally been well below the provincial government's target escapement of 35,000 fish. However, in 1998, the total size of the Skeena summer-run steelhead stock was in excess of 65,000 fish, indicating that reductions in commercial-fishery interception rates can increase steelhead escapement.

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Harvest Regulation: Balancing Production and Biodiversity Goals

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Gauntlet Net fisheries

Pool Sports/Troll Hook-and-Line Fisheries

Aboriginal/Sports in-River Fisheries (Variety of Gears)

Through most of this century, the development of salmon fisheries and fishing methods has been accompanied by efforts to regulate harvesting to ensure sustainable production. In recent years — to some degree at least — regulatory efforts have also been geared to maintain the biological diversity of the production system.

With the development of various "gear-types" (seine, gillnet, troll) over the years, and as various "sectors" (commercial, sports, Aboriginal) emerged, federal fisheries managers adopted a second basic regulatory goal — to allocate available harvest "fairly" among the competing fishing interests. Much of the complexity that we see in the current management system arises from the difficult job of trying to balance production, biological diversity, and allocation goals. This balancing problem has been made more difficult by a side effect of regulatory practices aimed at conservation: regulations that restrict where and when fishermen can pursue fish tend to intensify competition among fishermen and create incentives to seek ever-more efficient and competitive fishing methods. "Improvements" in fishing methods (increasing harvesting efficiency) have in turn forced fisheries managers to impose further restrictions on where and when fishermen can pursue fish. As fisheries managers face increased difficulty in meeting all allocation and conservation goals, a "vicious circle" develops, and an unfortunate response to the problem has been the attempt to try and help the fish catch up to fishing pressure, rather than adjust the fishing pressure. "Helping the fish catch up" has meant enhancing productivity, with hatcheries, the construction of artificial spawning channels, and other, costly "production side" responses. These measures often have not resulted in any net gains or solved any long-term problems. Often the wild fish have just been replaced by fish from enhanced runs. Enhancement has further and severely complicated the regulatory balancing problem.

If all we were concerned about were biological production, and protecting the production potential of all stocks (biological diversity), we could scrap the existing, crazy quilt regulatory system and harvest each spawning run as it approached its spawning grounds. Anything short of this extreme will involve serious "mixed-stock" fishery problems, or at least the acceptance of some tradeoff between higher catches and the protection of less-productive populations.

It is too simplistic to think that the only alternative to "mixed-stock" fisheries is the establishment of

"terminal fisheries" near the mouths of major rivers. River-mouth fisheries are not equivalent in their precision to fishing at the mouths of spawning rivers, where "clean" terminal fisheries can be conducted, such as for Smith Inlet sockeye, and Nimpkish and Nitinat chums. In fact, some of the "dirtiest," least selective and most destructive mixed-stock fisheries have been conducted at the mouths of major rivers, such as the Skeena and Fraser Rivers, where many stocks and species are still highly mixed.

To develop practical alternatives to those mixed-stock fisheries in order to prevent overharvesting and prevent erosion of biological diversity, it is important to closely examine the conservation impacts of existing harvest and regulatory system to see if it might be restructured to reduce risks to biological diversity, and to make fishing "safer" and more selective.

At present, the harvest and regulatory system has three major components: 1) Gauntlet net fisheries; 2) Pool fisheries (sports fisheries, commercial troll fisheries), and; 3) In-river Aboriginal and sports fisheries. The following subsections describe each of these fisheries in some detail and comment on key conservation issues they raise.

Gauntlet Net fisheries

Aimed mainly at sockeye, pink, and chum salmon, these fisheries involve seine nets and gillnets, deployed in short openings in relatively confined areas along the homeward migration routes of salmon runs. The basic concept in managing these fisheries has been to make each fishery opening small enough, in time and area, so that only a limited portion of the total run is exposed to the fishery.

The biggest gauntlet fishery in BC is for Fraser sockeye and pink salmon. This gauntlet stretches from Alaskan areas off Noyes Island, to BC areas in the Queen Charlotte Islands, to Johnstone Strait and Juan de Fuca Strait "entrance fisheries," to Georgia Strait and Fraser River mouth areas, and finally to upstream areas within the Fraser River. Fish destined to the Skeena River face a shorter gauntlet of fishing areas, from the Queen Charlotte Islands and Southeast Alaska into and along the River. Other major commercial gauntlet fisheries (central coast, Rivers and Smith Inlets, Barkley Sound) involve fish being exposed to harvest in just one or two ocean areas, and one or a few in-river Aboriginal fishing areas.

A key and distinguishing feature of all the gauntlet net fisheries is "in-season management," involving the use of test fisheries, catch statistics, and other monitoring programs such as acoustic counting during the run, to adjust the fishery openings so as to more closely meet exploitation-rate, escapement, and allocation goals.

Historically, there have been at least three major suggestions for improving the gauntlet fisheries to better meet conservation objectives. First, commercial gears could be changed to make them more selective or capable of releasing non-target fish. Second, fishery openings (areas and times) could be reduced greatly in size, and many more of them created, to make each fishery safer and to provide more in-season opportunities both for the fishing fleet and for management adjustments. Third, in-season monitoring and assessment procedures might be improved considerably, especially by creating new "fishing for information" fisheries, so as to improve stock-size estimation for both allocation and conservation objectives.

By the late 1990s, fisheries managers had gone about as far as is physically possible to adjust net fishery

openings so as to avoid interception of non-target stocks and species. With existing amounts, sizes and types of fishing gear, there was no management flexibility left in major fisheries. Fraser sockeye and pink openings that inadvertently take coho, chinook, and steelhead cannot be reduced much more without major allocation impacts.

Faced with these management challenges, the Minister of Fisheries and Oceans has recently instructed staff to ensure that selective fisheries should become the "cornerstone" of salmon management on the BC coast. Clearly, major changes in commercial fishing practices should be expected in the coming years, and the "selective fishing" initiatives arising from this new policy initiative should not be seen as merely a way to protect a few coho salmon. The shift to selective fishing practices likely marks the beginning of a complete change in the way salmon are harvested commercially. It is impossible at this time to predict what new innovations and technologies the fishing industry will develop; the key policy issue is how to arrive at ways of encouraging innovation and change in a socially, economically and conservationally responsible manner.

The idea of replacing existing fishery openings with more, smaller fishing opportunities has come to be called the "little bites" approach. This concept arose largely because of a near disaster that occurred during the 1994 Fraser River sockeye fishery. As sockeye approached the coast that summer, fishery managers expected a relatively small proportion of the run to traverse the Johnstone Straits fishing grounds at each time when fishery openings were planned. But the fish were apparently moving more slowly than usual, and in particular an unusually high proportion of the run accumulated in Johnstone Straits prior to a major opening. That opening thus resulted in both an unexpectedly high catch, and a much higher exploitation rate than usual for any one opening. It was not recognized immediately that this had happened. The high catch was interpreted as meaning the run was larger than usual, instead of being interpreted as a run that was more vulnerable to overfishing than usual. Run size estimates were adjusted upward, and further fisheries were planned — this is exactly the opposite of what should have been done. Luckily, test fisheries in the Strait of Georgia revealed that the stock had in fact been hit hard before reaching the Fraser River mouth, and disastrous overfishing was avoided. Events like this could be viewed as a testimony to the importance of test fisheries, but unfortunately test fisheries have not been all that reliable either.

There have been a variety of proposals and field tests for methods to improve in-season assessment of abundance. These range from providing explicit harvest allocations to "new" fisheries operating in locations and with gear especially suited to provide abundance index information. The shortfall in DFO's capability to adequately enumerate and assess stocks and fisheries means that help from industry and local interest groups should be sought. To date, DFO has failed to capitalize on co-management opportunities and proposals developed by industry. An apparent impediment has been concern about allocation impacts. Local stewardship and co-management provides opportunities to improve management and, in the longer term, fish production.

Pool Sports/Troll Hook-and-Line Fisheries

Historically, ocean hook-and-line fishing was aimed mainly at actively-feeding immature chinook and coho salmon, but in recent years, sports and troll fisheries have become quite efficient at taking maturing, migrating fish of the other salmon species as well. Fishing over large areas and with relatively long openings, the hook-and-line fisheries can generate quite high total exploitation rates for many stocks. Increasing

efficiency of commercial troll methods, especially for sockeye and pink, led to these fisheries being progressively restricted in place and time — they became more like gauntlet net fishery openings, resulting in high exploitation rates on limited percentages of total runs.

In addition to measured exploitation, hook-and-line fisheries can kill large numbers of small fish ("shakers") and fish from protected stocks, because of hook-and-release effects. There have not been good long-term programs for measuring the number of fish released, nor has it been practical to obtain good estimates of the mortality rates of these fish. Recent DFO studies have provided disturbing evidence that mortality rates of hooked-and-released fish may be considerably higher than previously suspected. Stock assessment procedures used by the chinook and coho technical committees of the Pacific Salmon Commission have attempted to account for "ghost" mortality not accounted for in catch and coded-wire-tag recovery statistics, but it is possible that the mortality rates assumed in such calculations have been too low.

A key feature of sports fisheries is "dynamic effort response": total fishing pressure is not limited by licence limitations. The uncontrolled numbers of fishermen can respond dramatically to changes in fish abundance. To some extent, this means that the sports fisheries can be "self-regulating," because fishing pressure will fall if stocks decline (and if the availability of hatchery fish does not keep attracting fishermen). Unfortunately, this effect is not as strong as we might hope, since sports fishermen vary widely in skill, and the best fishermen (who take the majority of the fish anyway) are the last to give up, and can even fish more efficiently when there are fewer competing novices.

In the past, hook-and-line fisheries (sport and troll) have generally not been adjusted within each fishing season, though commercial troll fisheries are now being watched more closely and closed if they intercept too many fish from stocks that need protection. Alaska has stirred some controversy through proposals for "abundance-based management," which would involve using test catch-rate information within each season to adjust allowable catches in response to unexpected high or low abundances. Beyond U.S.-Canada allocation questions, however, there is concern about whether such an approach would be biologically sound, and in particular, whether test catch-rate information would provide a good measure of abundance, and whether local variations in abundance reflect overall stock size or simply north-south shifts in fish distribution.

Aboriginal/Sport in-River Fisheries (Variety of Gears)

In-river fisheries have been controversial in recent years because of allocation issues, but the presence of "priority right" Aboriginal fisheries in upriver areas add significant difficulties to the management system that has developed in BC over the years. First, Aboriginal communities enjoy a "priority" in the allocation of fish surplus to escapement needs, but Aboriginal fishing grounds are generally situated at the end of the gauntlet line. The recognition of Aboriginal fishing rights has added a measure of difficulty in managing fisheries in a way that is consistent with the exercise of those rights. Fisheries managers are also expected to carry out allocation decisions, within each fishing season, on relatively inaccurate estimates of the total number of fish that can be safely harvested. Managers must scale back other fisheries so as to be confident that enough fish will reach river areas to meet Aboriginal allocations plus escapement goals. Ultimately, it may be that the only way to address this complexity and ensure public confidence in the accuracy of programs to assess in-river catches will be to radio-tag a large number of fish to determine how many of these fish are removed

short of their spawning grounds.

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Long-Term Strategies for Stock Rebuilding and Sustainable Harvest Management: Fixed Escapement Goals, or Fixed Exploitation Rates?

For every salmon species, there are at least some populations that have been over-harvested or severely reduced through historic habitat damage and other environmental effects. Most visible are coho, Rivers Inlet sockeye, Fraser River off-cycle sockeye, Strait of Georgia chinooks, Central Coast and Queen Charlotte Islands chum, and Strait of Georgia pinks. With public support for protection of these stocks, DFO will be more successful in ensuring that harvest practices will become more selective, so more stocks can be protected from incidental capture. With habitat restoration efforts, we should soon see many opportunities, not only to prevent further erosion in stock structure, but also to rebuild populations to more productive and safer levels. Just how should we go about the rebuilding and long-term harvest management process? There are two strategic options: effective harvest management, and deliberate enhancement of productivity so as to speed up the rebuilding process.

We should not and probably cannot count on hatcheries and spawning channel technologies to quickly rebuild populations. Temporary enhancement can be effective in some local circumstances, but over the long-term, highly productive artificial production systems can be a dangerous and costly substitute for a healthy natural production system. Further, there is simply too much evidence that enhancement efforts start out as just a little helping hand, then become permanent problems in themselves by providing excuses for not reducing exploitation rates. Large, permanent hatcheries and spawning channels may contribute directly to conservation problems, not only by providing an excuse to allow higher harvest rates, but also because enhanced fish compete directly with wild fish for the same resources, in the same rearing environments.

However, enhancement is not just big hatcheries and spawning channels. It includes a wide array of other tools that could be used for conservation. If they meet conservation and fisheries management criteria, these enhancement tools can be an asset instead of a liability. The tools can be used prescriptively to meet specific stock and habitat needs. The tools range from obstruction removal and fishways to habitat restoration and side channel development. They can include marking and outplanting for production and information. These valuable tools will likely be the key to rebuilding and managing stocks and addressing the diverse fishery and habitat management problems.

When it is recognized that a population is at far lower levels than it should be, and that continued high harvest rates will prevent the stock from rebuilding, there are two strategic options for harvest management: (1) the "fixed escapement" strategy, which is to stop harvesting entirely until escapement has recovered to long-term target levels, then to manage the population so as to achieve as close to the target escapement each year as possible; and (2) the "fixed exploitation rate" strategy, which reduces the harvest enough that the exploitation rate (percent harvest) is near the most desirable rate, and allows the stock to rebuild, although more slowly.

Fixed escapement strategies have some desirable properties. They return stocks to healthy levels as quickly as possible, and over the long-term, they result in the largest possible average harvest.

However, they have at least four severe drawbacks: (1) they can be economically and socially destructive if the rebuilding period is more than a few years; (2) they cause high interannual variation in catches, which again can be economically destructive; (3) they can result in inappropriate escapement levels if there are long-term environmental changes in habitat carrying capacity, and if these changes are not reflected in regular adjustments in escapement goals (which in turn can involve especially expensive and difficult monitoring costs); and (4) they are relatively costly to implement, generally requiring more elaborate in-season management procedures to adjust stock-size estimates and adjust catches so as to come reasonably close to escapement goals.

Fixed escapement policies are rarely applied in contemporary fisheries. An exception is in Alaska, but even there the managers do not even come close to practicing what they preach (Alaskan salmon exploitation rates are more stable than would be the case if they were actually successful at implementing fixed escapement rules).

Fixed exploitation rate strategies also have a number of desirable properties. They provide for at least some harvest most of the time; they lead to considerably less variable harvests from year to year; and they allow population size to "track" changes in marine and freshwater carrying capacity, even if the management system does not explicitly measure or detect such changes as they occur. They are also relatively inexpensive to implement, by varying fishing area sizes and times to limit proportions of fish exposed to exploitation risk.

However, fixed exploitation strategies also have serious disadvantages. Continued harvesting exerts a "drag" on recovering populations that can very greatly delay recovery. As an example, Strait of Georgia chinook might recover to 1970s levels in eight to 12 years without harvesting, but the same result would take 20 to 30 years under exploitation strategies fixed at "optimum" for long-term yield. Another disadvantage to fixed exploitation strategies is that exploitation rates cannot be carved in stone (truly "fixed"), but must instead be adjusted regularly to account for persistent changes in productivity. Such factors include those that cause persistent changes in freshwater and marine survival rates. As an example, coho might be able to sustain 50 percent exploitation rates under typical historical marine survival conditions, but with current marine survival conditions, most populations should now be harvested at less than 20 percent, and some should not be exploited at all. Determining appropriate exploitation rates, meanwhile, can involve relatively expensive biological monitoring programs.

To implement effective exploitation rate strategies, DFO staff would need to undertake a number of tasks

that have not been evident in recent reports, including: (1) a major, coastwide, all-species analysis of stock-recruitment and other productivity information in order to define clear exploitation rate goals for all stocks and fisheries; (2) ensure that existing exploitation rate monitoring programs (catch, escapement, coded-wire-tagging) are maintained, and at least some programs are substantially improved (escapement inspections, CWT sampling for sports fisheries); and (3) carry out annual updates and reviews of productivity information for all major stock groupings, so as to detect productivity changes and respond to them as quickly as possible.

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